DRAFT WORKING PAPER

Assessment of Possible Effects of Construction Blasting at Whites Point Quarry and Marine Terminal on Marine Mammals in the Bay of Fundy

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Context

The Whites Point Quarry and Marine Terminal project is currently undergoing a panel review under the Canadian Environmental Assessment Act. Concerns have been expressed by stakeholders that this proposed activity may have an impact on marine mammals in the Bay of Fundy. The Panel is likely to request DFO advice on this topic. In order to be prepared to answer any questions that may arise during the CEAA panel review, Habitat Management Division (Maritimes Region) has requested a DFO Science review of the potential harmful effects of onshore blasting at Whites Point Quarry on marine mammals, and advice on mitigation and monitoring. In particular:

- What is the potential for harmful effects on marine mammals beyond a 500m distance from the blasting site resulting from the sounds of blasting proposed for Whites Point Quarry?
- What is the potential for physical effects on endangered marine mammals beyond a 2500m distance from the blasting site resulting from the sounds of blasting proposed for Whites Point Quarry?
- What is the potential for behavioural effects on endangered marine mammals beyond a 2500m distance from the blasting site resulting from the sound of blasting proposed for Whites Point Quarry?
- How would mitigation activities currently proposed to be conducted in association with the blasting operations change the potential for impact on marine mammals?
- What monitoring could be conducted to validate the results of this assessment?

Issue

Construction of Whites Point Quarry and Marine Terminal will require in-ground blasting within close proximity to the Bay of Fundy shoreline. All blast locations are on land and no closer than 70 m from the high tide mark. Whites Point lies approximately 22 km from the center of the Grand Manan Basin summer/fall congregation area of the endangered northern right whale. The presence of an endangered marine mammal species within a few miles of the site requires special consideration. A colony of harbour seals at Crowell's Cove has been known to haul out at a site within 3 km of the proposed blast site.

Proposed mitigation includes a 500 m safety zone which will be monitored for marine mammals by experienced observers from shore-based sites. Blasting will not knowingly occur if marine mammals are seen to be present within this zone. A trained observer will also be employed to ensure no explosive is detonated when an endangered marine mammal (such as a northern right whale) is sighted within 2,500 meters of the blast site.

Assessment

Assessment Framework

The questions posed by Habitat Management will be answered in the context of a assessment framework developed specifically for this purpose.

Assessment of risk to marine mammals will be conducted using a source-pathway-receptor approach and the use of regulatory and other environmental benchmarks to define what may represent a significant and therefore unacceptable biological impact. Scientific expertise will be used to ensure that assumptions and uncertainties are clearly identified and addressed. For a risk of impact to exist, there must be a plausible relationship between the source, which in this case is the explosive charges; the pathway, i.e. the mechanism by which the source and receptor come in contact; and the receptor, which in this case would be the marine mammals likely present in the Bay of Fundy. Details on the characteristics of source, pathway, and receptor that will be used to conduct this assessment are provided in Table 1.

Source: Blasting Characteristics
- Source Location
- Source Intensity
- Detonation Timing
- Scheduling
Pathways: Sound Energy Propagation
- Possible Sound Energy Pathways
- Influence of Environmental Conditions
- Propagation Modelling
Receptors: Marine Mammals
- Occurrence
- Acoustic Sensitivity
- Biological Effects
Mitigation and Monitoring
- Mitigation
- Monitoring

Table 1. Assessment Framework for Effects of Onshore Blasting on Marine Mammals.

Source: Blasting Characteristics

Source Location

For the assessment of blasting on land, the distance of the source from the high tide mark will be used to determine the source levels entering the marine environment. Sound propagation paths will include air-to-water, rock-to-water, the latter including interference effects from reverberation within the water column itself. Where there are multiple charges, the relative location of these charges will be used to determine the likely overlap of sound/pressure waves – with a particular focus on the potential for constructive interference resulting in higher than anticipated sound levels. To resolve this issue, information on source location will be evaluated in combination with information on blast timing (see below).

For the Whites Point Quarry project, all blast locations are more than 70 m from the ordinary high tide line. The 56 initial charges are to be laid in a 2.7 m by 2.7 m configuration with hole depths between 7.3 and 8.8 m (see Figure 1). Subsequent blast configurations are not known.

Source Levels

Explosive detonations, while carefully controlled, are influenced by a variety of factors that make accurate determination of source levels difficult. For determination of pressure levels propagated through the air, the source is best described by its size, i.e. the size of the charge can be associated with an estimated concussion some distance away. For this paper, we are interested in the sound propagation from an onshore detonation into the marine environment. The role of multipath propagation, discussed in more detail below, makes a simple model of blast sounds based solely on charge size problematic.

For the Whites Point Quarry project, the load per hole is proposed as 45 kg ANFO explosives at 4.6 lbs/foot. The concussion from the air blast is estimated to be 128 dBA or less within 7 meters of the nearest structure not located on the site. [additional info needed…]

Detonation Timing

Blast timing will influence both the levels of sound entering the receiving environment and the likelihood that the sound would be received by some receptor. As mentioned previously, timing of individual blasts will influence the cumulative energy produced in terms of the potential for beam forming, i.e. where sound from multiple sources is emitted from a comparatively small source area such that a receiver at some distance might perceive the sound as a single source.

In the Whites Point Quarry project, blasting may be conducted at any time of the year. Blasting will not be conducted on Sundays or between 1800 and 0800 hours for social reasons. The original blasting plan was to deliver an average delay between blasts of approximately 25 ms, but this was subsequently reduced to 8 ms for safety reasons.

Beam forming of energy could occur whenever the sound propagation interval between any arbitrary pair of shot holes exceeds the pair-specific inter-hole delay time. Assuming a local propagation velocity of around 3 km/s, sound should propagate across the shot pattern largest dimension in about 10 ms or so. Therefore some degree of "beam forming" is still theoretically possible. However, preliminary examination does not indicate any instances where sound energy would be beamed straight at the nearest part of the coastline. In part, this may be due to the specific layout of the lines and the onset of the detonation sequence at the westernmost corner (see Figure 1).

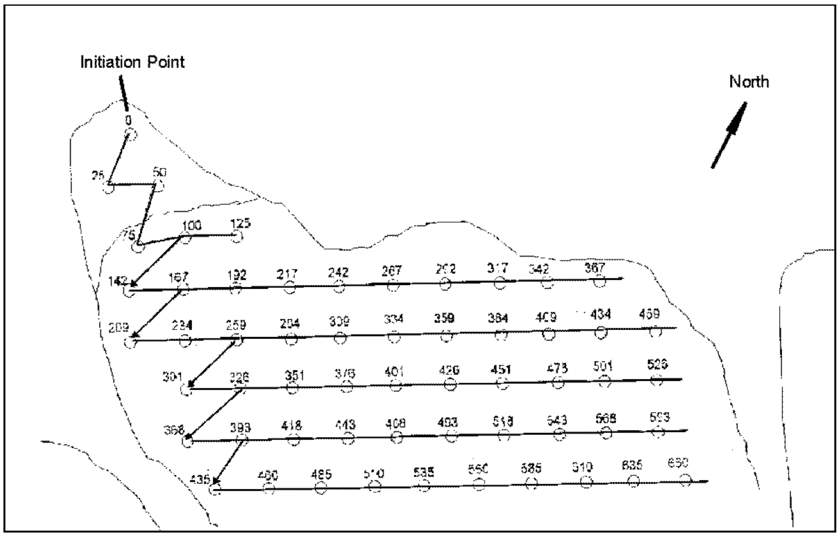

Figure 1. Proposed Shot 1 Initial Sequence.

The modification to produce a minimum of 8 ms delay between any two blasts over the entire pattern might be less effective than 25 ms delays but far better than no delays, i.e. simultaneous detonation of all shot holes.

Scheduling

Blast schedule will influence the potential for cumulative effects of multiple exposures on receptors present in the vicinity of the blast site.

For Whites Point Quarry, the proposed frequency of blasting during quarry start-up will be once per week and once every two weeks during full production. Thus, these acoustic events will be temporally isolated, in contrast to the continuous or semi-continuous (over periods of weeks to several months) transmissions that are characteristic of offshore seismic exploration.

Pathways: Sound Energy Propagation

Possible Acoustic Pathways

In this situation, acoustic pathways which could result in sound exposures that have the potential to cause impacts to marine mammals include:

- Sound waves propagated through the air to be received by marine mammals situated at the ocean surface or at nearby haul out sites.
- Pressure waves propagated through substrate and then through the water column to be received by submerged marine mammals.
- Vibrations propagated through substrate to be received by marine mammals that may be resting on the sea floor [considered highly unlikely].

Multi-path considerations, i.e., sound propagation through multiple pathways to reach a receptor, will be important. For example, it is possible that energy may propagate through the substrate, into the water column and directly to a receiver *or* pressure waves could also reflect off the ocean surface before reaching the same receiver. Another example of multi-path propagation can occur when underwater sounds are transmitted both directly through the water, and in a parallel direction through the sea bottom; this has been true for seismic sounds transmitted through both water and the subsea permafrost in the Arctic ocean (see review in Lawson and McQuinn 2004).

Within the first kilometer or two, acoustic energy is communicated into a wedge-shaped deepening water column from the underlying substrate. The combined effects of direct path energy and energy reflected off the water surface are probably dominant but more complex multi-path reverberation effects will also be present. The presence of shear elasticity in the substrate would appear to allow the substrate energy to be more efficiently coupled into the water column than in the case in which shear is absent.

Beyond a few kilometers range we are most likely dealing with a propagation problem for energy already communicated into the water column. Wave guide dimensions and sound speed structure existing within the water column could be important for energy propagation to ranges of tens of kilometers. Sound speed structures could tend to refract sound into the comparatively lossy bottom or, conversely, to isolate the water column propagating sound from such interactions. This issue has not been quantitatively explored.

Environmental Conditions

The physical environment in which a blast is situated will play a major role in the likelihood that energy will be propagated towards some receptor in a manner sufficient to cause biologically significant impacts. In this case, the physical environment under consideration includes the bedrock in which the explosives are situated, the substrate through which energy is propagated between the blast site and the marine environment, the characteristics of the water column and underlaying seafloor, topography and bathymetry, and possibly the atmospheric conditions which may influence the propagation of airborne sound waves.

For the Whites Point Quarry project, the initial blast location is situated on Jurassic north Mountain basalt bedrock that underlies the entire quarry and extends into the nearshore marine environment. The intertidal zone is rocky with a well established macroalgal community. Approximately 50 m offshore, there is an area with a layer of sand covering the bedrock with some outcrops and boulders. Water depths at distance from the lowest normal tide are provided in Table 2. It is important to note that the geometry, i.e. water depths at a given location and distance to water edge, vary over the tidal cycle.

Table 2. Water depth at distance from lowest normal tide.

Water Mark (m)	Depth (m)
60	2
120	5
180	10
240	20
540	30
1020	40
1380	50
1620	60
2580	80
4020	100

Propagation Modelling

In the absence of field measurements, determination of the propagation characteristics of explosive sound energy through bedrock into the marine environment must rely on numeric modelling. Ideally, such modelling would take into account source characteristics, bottom topography, water column properties, and ambient underwater noise levels.

Some sound propagation modelling has been conducted for proposed Whites Point Quarry project (Hannay and Thomson, 2003). This modelling predicts that "…the pressures at even the closest location in the water are not expected to exceed 50 kPa. If the blasts are performed within 3 hours of low tide then the maximum pressures will likely remain less than approximately 25 kPa in the water." It also describes the rise time of the pressure wave: "…in this situation, rise time increases with increasing distance from the blast." Long-range sound propagation estimates were not provided.

At 500m range within the water column, successive pressure pulses at 8 ms separation may be sufficiently closely spaced to partially overlap; however, the main effect would be to extend the length of the resultant superimposed pulse rather than to increase its amplitude.

No ambient noise measures have been made in this area. If there is a relatively high level of natural and pre-existing anthropogenic underwater noise, blast sounds might attenuate to these higher background levels more quickly than in quieter areas. However, without ambient noise measures we cannot assume this to be true.

Sound propagation modeling has made use of a reference to Oriard (1985), in particular Figure 1 in the Oriard paper is provided as Figure 3 in Hannay and Thomson (2003). While the data in this figure quantitatively agrees with DFO calculations when strictly interpreted as an 'energy ratio' as labelled. However, Oriard interprets 'energy ratio' as "the squares of the amplitudes of reflected and transmitted waves relative to those of the incident waves." This interpretation, which is used by Hannay and Thomson in the caption to Figure 3, is thought to be incorrect. Hannay and Thomson do qualify the equivalence with the word "approximately". DFO calculations show that the amplitude of the water transmitted P wave is lower than that stated by Hannay and Thomson, although higher than that calculated neglecting shear in the substrate altogether.

Conclusions:
Blast rms I don't believe "rms" has been defined. It should be explained. levels may be approximately 175-180 dB at a distance of 500 m from the source, at least when not considering the effects of partially overlapping multiple impulses discussed earlier.

The modeled RMS pressures at 500 m (180 dB) and 164 m (197 dB) lead to logarithmic RMS pressure decay of -35 log r. This approach gives 260 m distance to 190 dB RMS, instead of the originally proposed 170 m.

Receptors: Marine Mammals

Occurrence

Table 2 shows the marine mammals listed on Schedules 1-3 of the Species at Risk Act that may be found in the Bay of Fundy during the proposed blasting at Whites Point Quarry. The most likely timing of their expected presence in the Bay of Fundy is provided, along with their current status under SARA.

Species	***Timing***	***SARA Status***
Northern right whale	June –November	Schedule 1: Endangered
Blue whale	June – November	Schedule 1: Endangered
Harbour porpoise	All Year	Schedule 2: Threatened
Fin whale	All Year	Schedule 3: Special Concern

Table 2. Timing and Status of SARA Marine Mammal Species in the Bay of Fundy.

Whites Point Quarry lies only about 22 km from the center of the Grand Manan Basin summer/fall congregation area of the endangered northern right whale. Small whales and seals have been observed within 1.6 km of shore. The blasting proposal reveals an active whale watching community, and the presence of humpback and right whales at 8 km from shore. Additional information submitted for the blasting plan suggested that a colony of harbour seals at Crowell's Cove is within 3 km of the blasting. DFO is concerned that there may be potential harmful behavioural effects on the colony during the breeding season. Blue whales are sighted occasionally.

Acoustic Sensitivity

Marine mammals are well known to be acoustic animals that react to and are adversely affected by noise (for a recent review see Lawson and McQuinn 2004). While critical injury and temporary hearing sensitivity changes could result from certain impulsive sound exposures, these have not been documented in free-living marine mammals. On the other hand, there have been many documented marine mammal behavioural reactions to anthropogenic sounds. For instance, some large baleen whales have exhibited behavioural reactions, primarily displacement, when exposed to blasting sounds.[1] If the same reactions occur with the right whales that have been sighted in this area, then there could be impacts on this endangered species through lost feeding or reproductive opportunities.

It is thought that baleen whales are more sensitive to low frequency noise than toothed whales. Further, seals are considered to be more behaviourally tolerant to loud sounds and to have less sensitive underwater hearing relative to many cetacean species. The US has adopted the use of 180 dB for the maximum acceptable exposure level to impulsive sounds for toothed whales, and 190 dB for seals. These were adopted to minimize temporary hearing threshold shifts and more extreme physiological damage. Subtle behavioural effects, especially for baleen whales, have been documented to occur at lower acoustic levels - particularly with longer exposure duration.

Biological Effects

O'Keefe (1985) provides injury curves (single shots in water) for various sized whales and for porpoises. Most of these curves are estimated based on exposure of dead terrestrial mammals rather than testing explosives on actual marine mammals. The curves for whales assume a charge of 4,536 kg detonated at 396 m and the curves for porpoises a 544 kg charge at 38 m. Making some reasonable scaling assumptions the danger radii for single shot hole 45 kg charges would be less than 1 km. The real range for a Whites Point detonation would likely be somewhat less considering the decked charge, poor quarry blast ground coupling, and rather inefficient transfer of acoustic energy across the land/water interface. Therefore, a safety radius of 2500 m, to be applied to "any endangered marine mammal", is very likely to prevent any acute physical damage to the vital body organs (lungs etc.) of any northern right whales in the vicinity from the detonation of a single shot hole fired in isolation**.** Again it is again unclear what the result would be from detonation of typically 50 + shot holes over ½ sec.

[1] The limited available evidence indicates that marine mammals, like humans, show less reaction to discontinuous noise pulses with a given peak level than they do to continuous noise at that same level (see review in Richardson *et al.* 1995). However, some species of baleen whales exhibited some avoidance of areas where there are noise pulses with received peak pressures exceeded 160-170 dB re 1µPa (SEL) which is near 156 dB re 1µPa (SEL).

Significantly, the O'Keefe estimates do not take into account damage to the hearing apparatus of the baleen-type northern right whale, a species which is assumed to be more sensitive to low frequency sound. The acoustic sound pressure levels at which permanent hearing threshold shift or every temporary hearing threshold shift occurs are unknown. Because even slight damage to the hearing mechanism could be of serious impact to marine mammals highly dependent on acoustics to socially communicate and locate prey – not to mention avoidance of ship traffic – the question of auditory damage is an important one.

Some behavioural effects, such as stampeding of seals could conceivably occur from a single exposure event and might have population consequences if they caused disruption to reproductive activity or the injury/abandonment of young.

Mitigation and Monitoring

Mitigation

Proposed mitigation measures includes use of a 500 m "no-blast" buffer zone for marine mammals. To establish this zone, an observer, experienced and/or trained in marine mammal identification, would be positioned at an elevated shore position at least 1 hr prior to the start of blasting. The observer's task would be to detect and identify marine mammals within 500 m of the blast site. The observer would wear polarized glasses and be equipped with binoculars to enhance visual acuity. A two-way VHF radio or cellular phone would be used by the observer to communicate with the blast coordinator. In practice, blasting operations would be suspended if the observer sighted a threatened or endangered marine mammal within the 500 m buffer zone, and would not resume until 30 min after these animals either were observed or were presumed to have left the buffer zone based on activity and swimming direction. Presumably, blasting would not occur if weather conditions did not permit observations to 500 m.

The 500 meter buffer zone for marine mammals, preferably all marine mammals and not just those that are officially listed by SARA, is a mitigation technique that **might** be effective. However, without measures of the underwater sound pressure levels and frequency characteristics during the earliest worst-cast blast operations to confirm accuracy of modelling, a more definitive answer to this question can not be provided.

Comment: Uncertainty remains with this issue.

While the behavioural buffer zone for endangered marine mammals (2500 meters)[2] is **likely** to be effective for a **single** blast, concern remains about the potential effects of exposures to multiple blasts – particularly in quick succession.

Comment: Uncertainty exists about effects from multiple blasts.

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[2] It is likely that even with an elevated position it will be very difficult for an observer to detect a marine mammal at a distance of 2.5 km. Even if conditions are optimal for viewing (e.g., low glare, low sea state, at least 7· 50 binoculars on a fixed pedestal), there can be whales and seals that can remain undetected - especially as they can swim underwater for kilometres without being detectable by surface observers.

Monitoring

Sound propagation modelling and analysis has been conducted for the initial proposed blasting arrangement. It is not clear from the proposal how "subsequent blasts will be designed based on the information gathered from monitoring the initial blast…" or how "…all blasts will be designed to meet or exceed the parameters set forth in your Blasting Guidelines" based on data collected on the initial blast. For instance if ground velocities monitored during the initial blast are lower than those predicted from the empirical formulas does this justify modifying the formula for future predictions? This might be eventually justifiable – but one should have more good quality data than that obtained from one proximate monitoring site during one shot to justify it. Depth of shot holes hence possible coupling will vary for future shots.

A "pre-season" test blast (Would the test blast be a single shot or multiple shots? This should be clarified. Test blasts should be as much as possible representative of the actual blasting being proposed) with calibrated acoustic measurements in the near and far fields will greatly contribute to our knowledge about the accuracy of propagation models used, and the potential effects of this operation on marine mammal behaviour.

Test blasts prior to the expected arrival of the right whales (during which underwater sound measurements are made and effective marine mammal monitoring is conducted) would allow expert assessment of the likely impacts of these blasts. If the sounds levels are undetectable at the nearest margin of the right whale area, and the buffer distances for marine mammal injury or severe disturbance are shown to be small, then perhaps the proponent can be allowed to conduct such blasts near the waterline in the summer. On the other hand, if sound levels are detectable at great distances, or are dangerously high at distances underwater for which marine mammal monitoring is ineffective, then the proponent may be required to modify their blasting protocols (smaller charges, fewer in sequence, shallower depths, further back from the shoreline) or schedule (conducted when right whales are less likely to be present).

Underwater sound measurements should be made at 500, 1000, and 2500 meters from the test blast site. At what depths in the water column should these sound measurements be taken? I believe N. Cochrane previously mentioned that surface measurements are not definitive. Ideally, the proponent should also measure sounds levels at the "edge" of the right whale aggregation area (what distance is this area from the test blast site?), although it is suspected that the sounds levels will attenuate below the ambient sound levels at this distance in this relatively shallow marine environment. Is monitoring of ambient noise necessary? If so that should be indicated here.

In addition to test blasting, pre-, during, and post-blast observations of the harbour seal colony during the breeding season when behavioural disturbances are likely to have the greatest risk of biological effects through separation of mothers and pups is recommended. These observations should be conducted by an experienced biologist.

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Longer-term or subtle behavioural effects, if induced in endangered right whales following blast sound exposure, will be very hard to detect and quantify. Such questions can be addressed only with a well-designed, broad-scale (and expensive) research programme no doubt well beyond the financial or logistical scope of this proposed operation.

Conclusions and Advice

While the distance of disturbance of marine organisms by sound may extend beyond the 500 m suggested in the Whites Point Quarry proposal, it is considered highly unlikely that blasting would result in harmful effects on marine mammals, endangered or otherwise, beyond 500 m. However, there is a high level of uncertainty association with this conclusion. A test blast (multiple shots or single shots?) prior to project initiation would help to validate the sound propagation modelling used to reach this conclusion and would significantly increase the level of certainty in short-range impact estimations.

Subtle behavioural effects on marine mammals are expected to extend beyond 2500 m from the blast site. However, these are not expected to result in overall changes to the distribution of the population or other population-scale impacts. There is a moderate level of uncertainty associated with this conclusion. A test blast as described above would also help to increase the level of certainty in long-range impact estimations.

Proposed mitigation, i.e. the 500 m safety zone for marine mammals and the 2500 safety zone for endangered marine mammals, is expected to reduce the potential for harmful impacts of blasting on marine mammals under good visibility conditions.

The following research and monitoring recommendations would help to verify the results of this assessment:

(1) calibrated blast sound measures in near- and far-field locations (and at depths of….) prior to operational blasting and arrival of endangered right whales in the Bay of Fundy. (do calibrated sound measures include measurements of ambient noise levels?)

(2) monitoring of marine mammal behaviour before, during, and after operational blasting – especially of known marine mammal aggregations, i.e. during seal pupping.

Sources of Uncertainty

Uncertainty in the sound propagation modelling.

It is still unclear from the Oriard model (Hannay and Thomson, 2003), whether the pressure levels experienced at 500 m and beyond where water depths, at least as gleaned from the charts above, become significant, resulting in less effective cancellation of the water surface reflection. Shot overlap also becomes a greater problem.

Questions remain as to the validity of Oriard (1985) results presented in Figure 3 of Hannay and Thomson (2003). The problem involves P to S wave conversions and reflections at the interface between the elastic solid and the overlying liquid. The only applicable and accessible literature treatment of this problem is in a 1960 translation of a book by L. M. Brekhovskikh (1980). A computer simulation of the problem based on Brekhovskikh's solution was set up by DFO. Using the parameters of Figure 3, good agreement for "Reflected P" and "P Reflected as S" with the Hannay and Thomson results is obtained over the full range of incidence angles. However, the critical "Transmitted P" values do not agree. This may be a typographical error in Brekhovskikh's "Transmitted P" formula since Oriard's three results, as a group, obey energy conservation while Brekhovskikh's do not. Brekhovskikh's "Transmitted P" result can be brought into accord with Oriard's by changing one exponent in the former's analytical formulation.

Once this error is corrected, a DFO computer simulation gives a pressure (amplitude) transmission coefficient of only 0.057 at an incidence angle of 80^0 compared to the easily derived value of 0.03 on neglecting shear in the substrate. The former value is much smaller than the upper estimate of 0.3 quoted by Hannay and Thomson (2003). It appears they neglected the acoustic impedance differences between the upper and lower media and the change in physical width of the energy beam in crossing the interface when they converted transmitted to incident P wave energy ratios into pressure transmission coefficients. If this is indeed the case, the acoustic pressure levels transmitted into the water are much lower than Hannay and Thomson have estimated.

Incidence Angle ^{0}	Pressure Transmission Coefficient
70	0.080
80	0.057
85	0.014

Uncertainty in the behavioural responses of marine mammals.
Marine mammals are individuals that may behave unexpectedly at times. It is difficult to account for these individual differences, and typically only general behavioural trends are considered in analysis of potential impacts. However, use of a trained observer to monitor the 2500 m and 500 m buffers should help to provide flexibility in response to any unexpected behaviours.

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